SPECIFICATION

FIELD OF THE INVENTION

0001 This invention relates to thermal electrical power generating station layout for generating stations which employ a Rankine cycle, more specifically for generating stations where the working fluid undergoes a phase change from liquid to vapour at the heat input stage of its cycle.

BACKGROUND OF THE INVENTION

0002 In current standard thermal electrical power generating stations, the four main subsystems of the plant, 1) the thermal energy source (e.g. a nuclear reactor or fossil fuel fired boiler or other thermal energy source excluding geothermal), 2) the steam/vapour generators, 3) the turbine or other Rankine cycle expander or prime mover and 4) the condensers are all installed at or very near the same elevation relative to each other. Large high-pressure feedwater pumps are employed to supply the condensed working fluid back to the steam/vapour generators after exiting the turbine and condensing. In particular in nuclear power stations the steam generators are the normal means of cooling the reactor; and since cooling of the reactor is critical to its safe operation, these complex and costly feedwater pumps with their attendant systems of valves, main and auxiliary power supplies and controls must be installed with multiple redundancy at every point of potential failure.

0003 Also in current standard nuclear power generating stations, the reactor vessel and its attendant equipment is installed at surface level in a large reinforced containment structure designed to hopefully protect the public from radiation danger in event of a) an operating failure of a reactor system and b) the reactor vessel from being breached by being struck by b) an aircraft in an accident or terrorist event or c) a military weapon launched by hostile groups or d) an attack with an explosive charge. However it is a) not

proven and b) highly questionable; whether this type of containment could withstand a direct strike by the largest modern civilian or military aircraft, or the latest of military amour piercing projectiles and missiles.

0004 In current wind turbine installations, fluctuations in wind power available cause the generating capacity of the system to be unreliable and uncontrollable. Also generators for many modern wind turbines are often undersized below the capability of the wind turbine because the frequency of wind speed events cannot economically justify installing a generator sized for peak output capability. Such installations would benefit from an economical auxiliary means of driving the generator during periods of less than optimal wind speed. Also many low-volume or spent petroleum sources are unexploited due to the difficulty or expense of transporting such petroleum to a point of sale. If a wind turbine in combination with a Rankine cycle engine could supply power locally or to a nearby point on a grid, many of these resources could be exploited economically.

0005 Finally many commercial or residential high-rise buildings could benefit significantly by burning their normal heating fuel supplies in a Rankine cycle turbine electrical generating system first, then capturing the exhaust heat from the expander to serve the local heating requirement. Efficient systems such as these can provide up to 75% of normal electrical load of a residential or commercial building and all required heating load from just slightly increased fuel inputs over older heating systems which burn the fuel directly. A simple, efficient and automated CHP system would benefit many occupants of tall buildings.

SUMMARY OF THE INVENTION

0006 It is an object of the present invention to increase the safety and reliability; and to reduce the capital, maintenance and operating costs of any type of thermal electrical generating station by installing the condenser of a thermal electrical generating station at a significantly higher elevation relative to the

steam generator(s) and primary energy source. This difference in elevation enables gravity to reduce or eliminate the need for pumping to supply feedwater to the steam generator(s).

0007 It is another object of the present invention to enhance containment of any nuclear reactor employed to generate a working fluid vapour for supply to a turbine or other Rankine cycle expander generator by installing said reactor in a sealable steel alloy lined containment chamber, said chamber being deep under the surface and preferably excavated into solid stable dry rock in an earthquake-free zone. Said containment chamber to be designed to withstand internal pressures of several MPa without failure of its sealing apertures. Said containment chamber to be further provided with closed circuit convection cooling loops preferably installed as passages behind the alloy lining of the containment chamber surfaces, and said cooling circuit to be capable of maintaining the internal pressure of the containment chamber below the withstand pressure of the aperture seals under any circumstances of reactor failure.

0008 For any embodiment of the present invention, let x be a fractional positive factor which may range from 0 to 1 and is selected to compensate for head loss due to friction in the working fluid and vapour piping circuit at rated flow, and let y be a positive or negative factor selected to alter the delivered working fluid pressure to the vapour generators sufficiently to allow either a relatively low power booster pump system and / or a flow reducing control valve system to safely and accurately control the actual volume of working fluid delivered to the vapour generator(s).

0009 For any embodiment of the present invention, by installing the primary heat source and its vapour generator(s) at an elevation significantly lower than the system vapour condenser (e.g. deep in underground chambers excavated from solid stable rock, on the side of a mountain at the base, or in the basement of a tall building etc.) at a level (1+x+y) meters below the condenser for each 10.1 KPa_g * (density ratio of working fluid vapour divided by density of working fluid liquid feed) of operating pressure required to feed the vapour generators with Condensate, gravitational acceleration will return the Condensate to the vapour

generator(s) at the required pressure to properly charge said vapour generator(s) automatically, reducing or eliminating the costly high pressure, high power consumption and high maintenance cost feedwater pumping systems. The design of the vapour consumer (e.g. the turbine or other Rankine cycle expander generator of a power plant) is then altered to be slightly smaller (and less costly to build) to compensate for altered vapour pressure and temperature conditions either at the inlet if it is at the (higher) condenser level or if it is the condenser, or at the outlet if it is at the (lower) level of the vapour generator(s). The amount of capacity reduction is calculated 1) for a steam turbine or other Rankine cycle expander-generator set as a) pumping losses due to the level difference between the vapour generators and the turbine or other Rankine cycle expander inlet, calculated for a steam circuit; in MPa as (the density ratio in kg/m sup 3 of the vapour generator inlet fluid vs. the riser inlet vapour); plus b) conduction, radiation and friction losses in the relatively long vapour risers connecting the vapour generator(s) to the turbine or other Rankine cycle expander or condenser. The amount of capacity reduction is calculated as a) pumping losses due to the level difference between the steam generator(s) and the turbine or other Rankine cycle expander inlet, calculated in MPa as

0010 $$1 * \frac{\text{density of the steam generator outlet vapour in kg/m sup 3}}{\text{density of the steam generator inlet feedwater in kg/m sup 3}}$$

0011 plus b) conduction, radiation and friction losses in the relatively long high pressure circuit connecting the steam generator to the turbine or other Rankine cycle expander.

0012 Example: In particular as the pumping loss calculation might be applied to a CANDU 6 PHWR installed at 485 m below the turbine and operating its secondary working fluid circuit at 4.7 MPa and 262 Degrees C, the pumping losses a) will be 0.126 MPa, which is 2.58% of the thermal power of the reactor, perhaps as low as 0.77% of electrical output, assuming approximately 30% thermal efficiency of the

turbine / generator set. Losses b) will depend on engineering choices for pipe layout, length, quality, size, and insulation quality. The turbine / generator set is then designed slightly smaller (and less costly) to compensate for reduced supply steam pressure and temperature from the high pressure riser(s). Unfortunately actual losses will be somewhat larger than this calculation since there is no reduction in the heat of vapourization of the working fluid using this plan, but the elimination of the parasitic power draw of the feedwater pumps also returns a large part of this. This plus the reduction in capital costs and increased safety of the reactor installation will more than compensate.

DESCRIPTION OF THE DRAWINGS

0013 On all figures, similar parts are referenced by the same reference number.

0014 In drawings which illustrate embodiments of the invention, Figure 1 is a plan of a first preferred embodiment of the invention as applied to a nuclear reactor installation site having the reactor in a containment deep underground. Figure 2 is a section through Figure 1 at A – A. Figure 3 is an elevation of a second preferred embodiment of the present invention, again as applied to a nuclear reactor installation site but having all parts above ground. Figure 4 is an elevation of a third preferred embodiment of the present invention, having the vertical separation of vapour generator and turbine or other Rankine cycle expander provided by the tower of a wind turbine generator. Figure 5 is an elevation of a fourth preferred embodiment of the present invention, having the vertical separation of vapour generator and turbine or other Rankine cycle expander provided by a high-rise commercial or residential building.

0015 In accordance with a first preferred embodiment of the present invention illustrated in Figures 1 and 2, by installing a nuclear reactor and its steam generator(s) in a deep underground containment chamber **2** excavated from solid dry stable rock at a level (1+x+y) meters **11** below the turbine or other Rankine cycle expander and condenser system **9** for each 10.1 KPa_g of operating pressure required to

feed the steam generators with Condensate, gravity will return the Condensate to the steam generator(s) (via one or more of several redundant feedwater pipe lines **14** possibly installed into dedicated vertical passages in the rock) at the required pressure to properly charge said steam generator(s) automatically without requiring costly high pressure, high volume, high power consumption and high maintenance cost multiply redundant feedwater pumping systems. Low power pumps or proportional flow valves **15** are used to manage Condensate flow into the vapour generators. Condensate pre-heaters may be installed wherever practical. Said underground containment chamber to be accessible by a vertical shaft **1** and horizontal drifts **6, 8** of sufficient proportion to allow passage of the largest apparatus during construction, fuel management and onsite storage **7** operations. Access within the containment during maintenance is provided via e.g. 5 MPa withstand pressure remote operable access hatches **4** into the containment chamber Thermal expansion loops, Condensate separation systems etc. may be provided for by excavating one or more short horizontal drifts **13** from the main access shaft across to the drilled shaft(s) **14** containing the steam riser pipes, or by installing these pipes in the main access shaft. Note that coolant reservoir **10** logically would be a controlled inlet / outlet system located some distance horizontally remote from the reactor location, with natural surface drainage away from the site. The proximity showed in drawings is for scale purposes only.

0016 The preferred embodiment of the present invention illustrated in Figures 1 and 2 also benefits from the following added improvements over standard reactor installation:

0017 i) Increased security and pressure withstand capability of the containment due to the reactor being installed deep under solid stable rock **17.** Provided reasonable access security is maintained it is invulnerable to most acts of terror and to failure due to aircraft accidents etc.

0018 ii) Passive high-pressure containment emergency cooling provided by cooling water fed by gravity from the surface reservoir **10** into tubes **3** connecting to coolant loops embedded into the grout behind the

steel lining of the underground containment, which then naturally vent the resulting steam by a continuous return line to a condenser / filter system (not showed) at the surface. The same or a similar cooling circuit will be used during normal operation to manage the operating temperature of the containment in a closed pumped coolant circuit. Coolant intake tubes **3** would logically not pass directly from the bottom of the reservoir to the underground heat exchangers but include a siphon loop at the surface, to ensure no flow via the drilled passages in which the pipes are installed. Suitable small emergency powered priming pumps or raised storage are then used for priming the siphon.

0019 iii) Passive high-pressure reactor emergency cooling provided by cooling water fed by gravity from the surface into a purpose designed emergency heat exchanger installed within or near the underground containment, which then naturally returns the resulting steam by a continuous return line to a condenser / filter system (not showed) at the surface.

0020 iv) Greater public protection from radiation hazard by installing massive emergency sealing door(s) **5** on any access drifts and risers communicating with the containment, which in a complete emergency failure such as a breach of the reactor vessel during operation, would close with sufficient force to cut and seal any pipes in their path, allowing time to e.g. fill the containment with a reaction poison such as borosilicate sand or borated water, gadolinium poisoned water, or to pour the entire excavation behind or below the emergency sealing door(s) full of treated concrete to completely block any possible release of contaminants, without loosing the capital invested in the turbine or other Rankine cycle expander / generator set.

0021 iv) Possibly licensing could be obtained for planned "decommission in place" of the reactor vessel and its machinery (and possibly the spent fuel) at the end of their design life by completely sealing off or backfilling the entire underground excavation after all installed systems are decommissioned.

0022 In accordance with a second preferred embodiment of the present invention illustrated in Figure 3, by installing a nuclear reactor and its steam generator(s) in a containment **2** at the base of a natural or artificial mountain at a level (1+x+y) meters elevation **11** below the turbine and condenser **9** for each 10.1 KPa_g of operating pressure required to feed the steam generators with Condensate, gravity will return the Condensate to the steam generator(s) (via one or more of several redundant feedwater pipe lines **14** possibly installed into trenches in the surface **18**) at the required pressure to properly charge said steam generator(s) automatically without requiring costly high pressure, high volume, high power consumption and high maintenance cost multiply redundant feedwater pumping systems. The turbine / generator set is then designed slightly smaller (and less costly) to compensate for increased steam backpressure at the vapour riser(s) to the condensers. The amount of size reduction due to pumping losses is lower in this configuration than in Figure 1 due to the lower vapour density of the exhaust steam vs. high pressure steam in the riser. It is calculated as a) pumping losses due to the level difference between the turbine and the condenser inlet, calculated in MPa as (the density ratio in kg/m sup 3 of the steam generator inlet feedwater vs. the riser vapour); plus b) conduction, radiation and friction losses in the relatively long vapour circuit riser connecting the steam generators or the turbine to the condenser. The configuration of turbine and generators may be changed (not showed in drawings) by moving the turbine and generator to the same level as the reactor and steam generators in which case the pumping losses, though theoretically lower due to the reduced density of the vapour rising in the lines to the condenser actually may need to be greater in this configuration to overcome the tendency for the turbine exhaust to condense within the riser pipe, creating a need for Condensate pumping losses. Losses b) will depend on engineering choices for pipe length, quality, size, and insulation quality. This configuration would make sense for a fossil fueled thermal power station as well.

0023 In accordance with a third preferred embodiment of the present invention illustrated in Figure 4, the required difference in elevation between the tower base and the generator housing of a wind turbine is employed to enable a low-cost low-maintenance auxiliary thermal power source **20** (e.g. a fossil fueled

boiler etc.) at or near ground level to provide power to an auxiliary closed turbine or other Rankine cycle expander circuit **21** connected to a turbine or other Rankine cycle expander generator **22** and condenser **23** at or near the top of the tower. Said auxiliary turbine or other Rankine cycle expander may be connected by gears and / or clutches to the existing gearbox **24** and electrical generator **25** of the wind turbine. The purpose of said auxiliary turbine or other Rankine cycle expander is to augment power generation from the wind turbine during periods of low wind, or of wind too strong to operate the wind turbine power source safely if the wind turbine can be disconnected from the generator while the generator still runs. For this purpose, a working fluid other than water may be employed to eliminate risk of damage due to freezing, to allow selective design variations in operating pressures and temperatures at all points in the working fluid circuit, and to possibly reduce the size and complexity of the condenser installation at the top of the tower. Gravity is then employed to partially or entirely pressurize the condensed working fluid supply to the said vapor generator at ground level from the condenser at the top of the tower. Flexible working fluid lines **21** capable of withstanding the same number of radians of rotation as the electrical power cables existing in the tower can then provide for required rotational orientation of the wind turbine if necessary. Auxiliary condenser cooling fans may then be required. This embodiment of the invention converts an unreliable weather-dependent generator into a reliable baseload generator with a significant proportion of energy provided by wind. A designer may also consider uprating the generator size relative to the wind turbine blade swept area in order to enable safe operation in stronger winds, thus improving the overall economics of the installation. This strategy is particularly useful in areas where fairly small amounts of sweet petroleum fuels are flared or not extracted because they may be uneconomical to transport as found.

0024 In accordance with a fourth preferred embodiment of the present invention illustrated in Figure 5, the existing difference in elevation between ground and the upper levels of a commercial or residential building **30** is employed to enable a low-cost low-maintenance thermal power generator **20** at a low level in the building to provide heated working fluid vapor to a closed turbine or other Rankine cycle expander circuit **21** connected to a turbine or other Rankine cycle expander **22** then a condenser **23** at the top of the

building. The turbine or other Rankine cycle expander then drives a generator **25** to supply all or part of the buildings electrical requirements. For this purpose, a working fluid will be selected to eliminate risk of damage due to freezing, to allow selective design variations in operating pressures and temperatures at all points in the working fluid circuit, to ensure public safety in the event of a leak of the working fluid, and to possibly reduce the size and complexity of the condenser installation at the top of the building. Gravity is then employed to partially or entirely pressurize the vapor generator near or below ground level with working fluid from the condenser near the top of the building. In this embodiment, the condenser may be partially or fully replaced by heat recovery systems generating heated water or air for space heat, domestic hot water or heat for other purposes to the building occupants.